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Acquisition of L2 morphology by adult language learners

Lilli Kimppa [a,b,*], *Yury Shtyrov* [b,c], *Suzanne C.A. Hut* [a,d], *Laura Hedlund* [a], *Miika Leminen* [a,e] *and Alina Leminen* [a,f]

[a] *Cognitive Brain Research Unit, Department of Psychology and Logopedics, Faculty of Medicine, University of Helsinki, Helsinki, Finland*

[b] *Center of Functionally Integrative Neuroscience, Department of Clinical Medicine, Aarhus University, Aarhus, Denmark*

[c] *Laboratory of Behavioural Neurodynamics, St. Petersburg University, St. Petersburg, Russia*

[d] *Department of Intensive Care Medicine, University Medical Center, Utrecht, the Netherlands*

[e] *Department of Phoniatrics, Helsinki University Hospital, Helsinki, Finland*

[f] *Cognitive Science, Department of Digital Humanities, Helsinki Centre for Digital Humanities, Faculty of Arts, University of Helsinki, Finland*

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ABSTRACT

Learning a new language requires the acquisition of morphological units that enable the fluent use of words in different grammatical contexts. While accumulating research has elucidated the neural processing of native morphology, much less is known about how second-language (L2) learners acquire and process morphology in their L2. To address this question, we presented native speakers as well as beginning and advanced learners of Finnish with spoken (1) derived words, (2) inflected words, (3) novel derivations (novel combinations of existing stem + suffix), and (4) pseudo-suffixed words (existing stem + pseudo-suffix) in a passive listening EEG experiment. An early (60 msec after suffix deviation point) positive ERP response showed no difference between inflections and derivations, suggesting similar early parsing of these complex words. At 130 msec, derivations elicited a lexical ERP pattern of full-form memory-trace activation, present in the L2 beginners and advanced speakers to different degrees, implying a shift from lexical processing to more dual parsing and lexical activation of the complex forms with increasing proficiency. Pseudo-suffixed words produced a syntactic pattern in a later, 170–240 msec time-window, exhibiting enhanced ERPs compared to well-formed inflections, indicating second-pass syntactic parsing. Overall, the L2 learners demonstrated a gradual effect of proficiency towards L1-like responses. Advanced L2 learners seem to have developed memory traces for derivations and their neurolinguistic system is capable of early automatic parsing. This suggests that advanced learners have already developed sensitivity to morphological information, while such knowledge is weak in beginners. Discrepancies in ERP dynamics and topographies indicate partially differing recruitment of

* *Corresponding author*. Cognitive Brain Research Unit, Department of Psychology and Logopedics, Faculty of Medicine, University of Helsinki, Finland.

E-mail addresses: lilli.kimppa@helsinki.fi (L. Kimppa), yury.shtyrov@cfin.au.dk (Y. Shtyrov), suzanne.hut@helsinki.fi (S.C.A. Hut), laura.hedlund@helsinki.fi (L. Hedlund), miika.leminen@helsinki.fi (M. Leminen), alina.leminen@helsinki.fi (A. Leminen).

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the language network in L1 and L2. In beginners, response differences between existing and novel morphology were scarce, implying that representations for complex forms are not yet well-established. The results suggest successful development of brain mechanisms for automatic processing of L2 morphology, capable of gradually attaining L1-like functionality with increasing proficiency.

1. Introduction

Acquisition of grammar and morphology is key in becoming fluent in a language, native or foreign. In many languages, grammar and word formation are realised by adding morphological affixes to stems (e.g., an inflectional suffix, such as '-s', added to 'cat' becomes plural form 'cat + s' and e.g., derivational agentive suffix '-er', added to a stem 'work' produces a noun 'worker'), stressing the central role of morphology acquisition in first and second language learning. In second-language (L2) acquisition and processing, however, morphosyntactic phenomena expressed through affixation have been identified as one of the most challenging tasks (e.g., DeKeyser, 2005), making it an intruiging research topic.

In native (L1) speakers, the question of processing morphologically complex words and their mental representations has been intensively studied both behaviourally and neurophysiologically for the past few decades. While the field is still largely Anglo-centric, there is a general agreement that regularly inflected words undergo combinatorial (parsing) and lexical processing, subserved by fronto-temporal brain networks (e.g., Bozic & Marslen-Wilson, 2010; Leminen, Smolka, Duñabeitia & Pliatsikas, 2018). The exact electrophysiological correlates of inflected word processing vary depending on the task and/or stimulus types, with the most commonly reported ERP components being left anterior negativity (LAN), N400, (syntactic) mismatch negativity (MMN), and P600 components (see, e.g., Allen, Badecker, & Osterhout, 2003; Bakker, Macgregor, Pulvermuller, & Shtyrov, 2013; Fruchter, Stockall, & Marantz, 2013; Lehtonen et al., 2007; Leinonen et al., 2009; Leminen, Leminen, Kujala, & Shtyrov, 2013; Leminen et al., 2011; Lück, Hahne, & Clahsen, 2006; Regel, Kotz, Henseler & Friederici, 2017; Stockall & Marantz, 2006; Vartiainen et al., 2009; Whiting, Marslen-Wilson, & Shtyrov, 2013; for a recent review, see Leminen et al., 2018). With respect to the processing of L1 derivations, most current models advocate combinatorial processing route, with behavioural evidence largely supporting this view. Yet, neural and electrophysiological evidence is largely discrepant, with a clear need for further investigation in both L1 and L2 speakers. Event-related potential/field (ERP/ERF) studies, using e.g., priming, lexical decision, and passive listening tasks, have interpreted their results as either supporting early parsing of derivations or full-form retrieval/simultaneous morpheme-based processing, with both morpheme-based and full-form memory trace activation taking place in L1 speakers (e.g., Cavalli et al., 2016; Fruchter & Marantz, 2015; Hanna & Pulvermüller, 2014; Havas, Rodriguez-Fornells, & Clahsen, 2012; Leminen, Lehtonen, et al., 2013; Leminen, Leminen, et al., 2013; Leminen et al., 2011; Lewis, Solomyak, & Marantz, 2011; Solomyak & Marantz, 2010; Whiting et al., 2013; Zweig & Pylkkänen, 2009).

1.1. *L2 processing of inflections and derivations: behavioural and electrophysiological evidence*

The question of how the brain of L2 learners with varying proficiency processes inflected and derived word forms is currently unresolved. L2 learners frequently experience difficulties with the grammatical aspects of their L2, demonstrated by, e.g., the omission of morphological features or a non-systematical application of morphological features (e.g., White, 2003). According to the Declarative/Procedural model, grammatical rules may be subserved by the procedural memory system (Ullman, 2001a), in contrast to the acquisition of lexical items, which requires the declarative memory system. For L2 learners, however, the acquisition of L2 grammar may (initially) load more on the declarative memory system, until sufficient L2 experience improves the acquisition of grammatical rules by procedural memory (Morgan-Short & Ullman, 2011; Ullman, 2001b). Relatedly, the convergence hypothesis (e.g., Abutalebi, 2008; Green, 2003) proposes that, on the neural level, L2 learners may process and represent their L2 in a more native-like manner as their L2 proficiency increases. Behavioural studies have shown evidence for L1-like inflected word processing and use of decomposition in L2 learners (e.g., Bosch & Clahsen, 2016; Gor & Jackson, 2013; Portin, Lehtonen & Laine, 2007). However, differences in the processing of inflections in L2 and native speakers have also been reported (e.g., Farhy, Verissimo, & Clahsen, 2018; Kirkici & Clahsen, 2013; Silva & Clahsen, 2008), possibly indicating larger reliance on storage than on combinatorial processing in the L2 learners ('Shallow Structure Hypothesis', e.g., Clahsen, Felser, Neubauer, Sato & Silva, 2010).

With regards to derivational processing approached behaviourally, reduced or no priming effects were reported for morphologically related prime–target pairs in proficient L2 speakers as compared to L1 speakers (Clahsen & Neubauer, 2010; Silva & Clahsen, 2008), which is taken as evidence of greater reliance on holistic processing of derivations in L2 as compared to L1 speakers. In contrast, several masked priming studies have reported comparable effects for derivations in both L1 and in L2 speakers (Diependaele, Duñabeitia, Morris, & Keuleers, 2011; Jacob, Heyer, & Veríssimo, 2017; Kirkici & Clahsen, 2013; Voga, Anastassiadis-Syméonidis, & Giraudo, 2014), interpreted as decomposition of derived words into their constituents in both L1 and L2 speakers. Dal Maso and Giraudo (2014) reported comparable masked priming effects

for L1 and L2 speakers (of varying proficiency) for derivations with frequent and productive affixes, while differences between L1 and L2 groups occurred only for forms with infrequent derivational affixes. The authors suggested that L2 learners are sensitive to morphological information, but they integrate it gradually with increasing proficiency. In a visual lexical decision study (Portin & Laine, 2001), both L1 speakers and early bilinguals showed shorter lexical decision latencies to transparent derived words than to matched monomorphemic words, interpreted as reflecting dual-route processing of derivations, i.e., processing both the full-form and the morphemes in parallel.

Since behavioural methods show only the result of the processing, ERPs are valuable in revealing online language processing, mostly due to their precise timing. They are also capable of revealing some effects not detected by means of reaction times. Available ERP evidence on morphological processing in L2 speakers has shown both L1-like and dissimilar processing. For instance, using a sentential violation paradigm, Hahne, Mueller, and Clahsen (2006) observed an early anterior negativity and a late P600 response for violations of regular L2 inflections, whereas violations of irregular inflections elicited an N400 effect. These ERP patterns were similar in the L1 and advanced L2 groups, suggesting comparable combinatorial processing versus lexical storage of regular and irregular inflected stimuli. An ERP repetition priming study with isolated inflected words found a similar N400 priming effect in both L1 and highly proficient Spanish-Catalan bilingual speakers, but the bilinguals showed a reduced N400 priming effect for irregular morphology (De Diego Balaguer, Sebastian-Galles, Diaz, & Rodriguez-Fornells, 2005). Moreover, early highly proficient Finnish-Swedish bilinguals were reported to exhibit larger N400 effects for correctly inflected versus monomorphemic words than Finnish L1 speakers in an unprimed visual lexical decision task (Lehtonen et al., 2012). In early bilinguals, N400 to inflected words with both high and low frequency differed from monomorphemic words, but in L1 speakers, the response to high frequency inflections did not differ from high frequency monomorphemic words (for similar behavioural findings see e.g., Lehtonen & Laine, 2003). This between-group discrepancy was explained by reduced exposure to each word in bilinguals as compared to L1 speakers due to the division of input between the two languages; i.e., the bilinguals' subjective frequencies for these word forms may be lower (Lehtonen et al., 2012).

Taken together, electrophysiological findings on L2 inflected word processing indicate that the underlying mechanisms may differ to some extent between L1 and L2 speakers, and processing of inflected words is less automatic and more laborious even in early bilinguals compared to L1 speakers. This indicates an influence of both proficiency level and age of acquisition (AoA) in the processing of inflections. It should be noted, however, that research on L2 inflection processing has focused on more advanced L2 groups than beginning learners. One ERP priming study addressing the role of proficiency in the processing of regular inflections reported morphological priming effects in the N400 time-window, whereas less proficient L2 learners showed no such morphological priming effect (Liang & Chen, 2014). This was taken to suggest that highly proficient L2 learners decompose regular morphologically complex words, while less proficient L2 learners might rely more on lexical storage. This finding is in line with ERP/ERF studies on phrase-level morphosyntactic stimuli, showing that in contrast with high-proficient L2 learners, low-proficient L2 learners do not automatically process morphosyntactic rule violations (Hanna, Shtyrov, Williams, & Pulvermüller, 2016), supporting findings of more L1-like syntactic ERP patterns with the attainment of higher L2 proficiency (e.g., McLaughlin et al., 2010; Montrul & Tanner, 2017; Tanner, McLaughlin, Herschensohn, & Osterhout, 2013).

Electrophysiological evidence on how L2 learners acquire and process derivational morphology in their L2, particularly at different levels of proficiency, is scarce. Deng, Shi, Dunlap, Bi, and Chen (2016) examined the effect of morphological knowledge on the processing of L2 correctly derived words and pseudo-derivations. Pseudo-derivations elicited a larger P600 response than correctly derived ones in the L2 group with high morphological knowledge, while in the L2 group with low morphological knowledge, pseudo-derived forms elicited a significantly more negative N400 component than the correct forms. Deng et al. (2016) suggested that L2 speakers with high morphological knowledge are sensitive to rule violations and apply decomposition, whereas L2 group with low morphological knowledge might depend more on full-form storage (supporting the DP model, Morgan-Short & Ullman, 2011).

To sum up, research on the electrophysiological processing of inflected and derived words with high and low L2 proficiency suggests that combinatorial processing could take place at the advanced level of L2. Due to the relatively low number of ERP studies using single-word stimuli, and the use of varying experimental paradigms, target languages, and grammatical categories, there is a clear need for further research. The differences in experimental paradigms (e.g., masked priming *vs* sentence reading) may also lead to distinct processing strategies and attentional effects, causing differences in the observed effects. A paradigm with low attentional and executive demands on the processing of the speech stimuli is needed in order to investigate the development and automaticity of L2 parsing. Since the vast majority of L2 research on morphological processing has been conducted in the visual modality, it is important to expand research to speech, the 'native' modality of human communication. A passive listening paradigm, with no task or requirement of focussed attention on the spoken stimuli, is capable to capture full-form versus parsing-specific ERP signatures of lexical and morphosyntactic processes, uncontaminated by any active task, attention variation or strategic biases (Gansonre, Højlund, Leminen, Bailey, & Shtyrov, 2018; Hanna et al., 2016).

1.2. *The present study*

Here, we examined neural signatures of morphological processing in L2 in participants with varying language proficiency. We focussed on the automatic processing of a wide range of morphologically complex stimuli, in order to get a comprehensive overview of L2 processing of morphological word forms. More specifically, we presented L1 speakers as well as beginning and more advanced L2 learners of Finnish with spoken (1) existing derived and (2) inflected words, as well as (3) novel derivations (novel combinations of real

stem + real derivational suffix) and (4) pseudo-suffixed complex forms (real stem + novel suffix). We time-locked our ERP responses to the onset of the suffix deviation point. This procedure has previously been used in several studies (e.g., Hanna & Pulvermüller, 2014; Leminen, Leminen, & Krause, 2010; Leminen, Leminen et al., 2011; Leminen, Lehtonen, et al., 2013; Leminen, Leminen, et al., 2013; Whiting et al., 2013), revealing even short-lived and focal morphology-related responses, undetected by the more traditional word-onset locked ERP quantification. We employed a passive listening 'multi-feature' paradigm (Näätänen, Pakarinen, Rinne, & Takegata, 2004; Sorokin, Alku, & Kujala, 2010), in which multiple suffixed word types were presented in alternation with monomorphemic stem words. Participants were instructed to ignore the spoken stimuli and instead focus on an unrelated visual task, thus removing stimulus-related attentional demands and task effects.

Importantly, previous studies using such a setup have shown it to be sensitive for probing neural memory trace activation of monomorphemic words, complex words, as well as (morpho)syntactic structures (e.g., Bakker et al., 2013; Leminen, Leminen, et al., 2013; Shtyrov, Kimppa, Pulvermüller, & Kujala, 2011; Whiting et al., 2013). More specifically, this paradigm is sensitive to stimulus lexicality, such that well-formed monomorphemic words produce larger responses than meaningless pseudo-words (Garagnani, Shtyrov, & Pulvermüller, 2009; Pulvermüller et al., 2001; Shtyrov, et al., 2011; Shtyrov & Pulvermüller, 2002). This lexical enhancement is proposed to reflect automatic activation of pre-existing word memory circuits compared to acoustically matched pseudo-words with no long-term memory traces (Shtyrov, Nikulin, & Pulvermüller, 2010). Long-term word memory traces are suggested to comprise distributed neural circuits in the language network, which are built through associative learning; i.e., connections are strengthened between neurons that activate automatically upon presentation of specific word input (Pulvermüller, 1999; Pulvermüller & Garagnani, 2014). The stronger the connections of the memory trace for a specific word are, the greater is the neural response when the word is encountered.

In the case of complex words, pseudo-derivations and incongruent derived forms produce smaller responses than real derivations, suggesting no memory traces for the full-form of pseudo-derivations as opposed to existing derived words (Hanna & Pulvermüller, 2014; Leminen, Leminen, et al., 2013). For combinatorial, (morpho)syntactic sequences, however, correct combinations of words or morphemes yield smaller responses than incorrect combinations in passive presentation (Brunelliere, Franck, Ludwig, & Frauenfelder, 2007; Hasting & Kotz, 2008; Hasting, Kotz, & Friederici, 2007; Menning et al., 2005; Pulvermüller & Assadollahi, 2007; Pulvermüller & Shtyrov, 2003; Pulvermüller, Shtyrov, Hasting, & Carlyon, 2008). This pattern has been observed not only for short phrases but also for regular inflections (Bakker et al., 2013; Leminen, Leminen, et al., 2013) and can be explained by automatic combinatorial processing of both word- and phrase-level complex sequences. That is, in (regularly) inflected forms, the co-occurrence of stem and affix would result in an associative link between them. At the neural level, this leads to pre-activation of the affix representation by a related stem, reducing the actual response to the affix when it finally arrives (Bakker et al., 2013). In complex pseudo-words, the stem has no neural link to the affix, leading to a relatively larger neural response as compared to real complex words. This dissociation between the two types of neurolinguistic contrasts enables probing the (morpho)syntactic combinatorial processing as opposed to activation of full-form representations (Cappelle, Shtyrov, & Pulvermüller, 2010). Previous studies with passive auditory setups have shown differences in the ERP responses to inflectional and derivational affixes, taking place already 100 msec after the suffix onset (Leminen, Lehtonen, et al., 2013; Leminen, Leminen, et al., 2013). This was interpreted as evidence for fully automatic decomposition of regularly inflected words, and, possibly, dual-route processing of existing derivations (Leminen, Leminen, et al., 2013, see also Whiting et al., 2013).

Crucially, when investigating spoken language, and especially morphological processing in different groups, it is important to allow for direct comparisons between suffixes in stimuli that provide a meaningful contrast against each other, both in their morphological and acoustic properties. Scrutiny of such contrasts within each group, rather than just comparison of responses between groups, excludes the confounds of any nonspecific overall between-group differences in event-related potentials to the spoken input. This approach enables analysis of response patterns and their differences within each group, the results of which can then be compared across groups as well.

Based on the existing evidence, we predict that:

1) Existing derivations (contrasted with novel combinations of an existing word stem and a real suffix that do not form a derivation in the language) elicit a larger negative response at 100–200 msec after suffix deviation point, in accordance with previous passive listening ERP studies that showed larger negative ERPs in the 100–200 msec range to existing derivations than pseudo-derivations (pseudo-stem + real suffix) and violated derivations (Hanna & Pulvermüller, 2014). This is hypothesised to reflect activation of pre-existing lexical full-form memory traces [although the possibility of parallel morpheme-based processing in a dual-route fashion cannot be ruled out (Leminen, Lehtonen, et al., 2013; Leminen, Leminen, et al., 2013)]. This response is predicted to be smaller to novel derivations that have no pre-existing memory traces of the full form. Rather, we expect the native speakers to decompose the new complex words into the existing suffix and the word stems (for ERP evidence on novel derivations with active reading and listening paradigms, see Leminen et al., 2010; McKinnon, Allen, & and Osterhout, 2003). The advanced L2 speakers are expected to demonstrate ERP response patterns similar to the L1 speakers due to the presumably acquired sensitivity to L2 morphemes (Deng et al., 2016). For the beginners, we predict no differences in the ERP responses between the novel and existing derivations, expecting them to process both types in a similar way due to the putative lack of morphological information in the L2 (Deng et al., 2016) precluding decomposition possibilities.

2) Inflected words are expected to elicit smaller ERP responses than derived words at the 100–200 msec latency in native speakers, due to weaker or even absent full-form memory traces for inflected words (Leminen, Leminen, et al., 2013). We also tentatively predict that advanced L2 learners process derivations and inflections in a fashion more similar to native speakers, as opposed to beginners, who are expected to retrieve the full-form of both complex types (Hanna et al., 2016; Liang & Chen, 2014; Clahsen et al., 2010). The processing difference is expected to manifest in ERP effects differing in amplitude and/or topography as compared to the native and advanced L2 speakers.
3) The comparison of existing inflections with pseudo-suffixed combinations (i.e., existing stems + pseudo-suffix) is expected to show no effects related to lexical activation, since purportedly, neither word type has a pre-existing full-form representation. Moreover, due to the non-existence of the pseudo-suffix in the language, we expect a (morpho)syntactic ERP pattern of greater response to the pseudo-suffixed words than inflections ~150–300 msec after suffix deviation point in the native speakers (Bakker et al., 2013; Hanna et al., 2016). That is, for complex pseudo-words (containing an unfamiliar stem–suffix combination), there are no neural links between the morphemes, leading to a larger neural response to the unfamiliar suffix compared to plausible inflections. We expect this ERP pattern to be elicited in the advanced L2 speakers, since recent findings with a similar experimental setup observed comparable combinatorial response patterns for L1 speakers and advanced L2 learners (Hanna et al., 2016). The beginners have only low morphological knowledge in L2 and are thus not expected to show morphosyntactic effects for pseudo-suffixes.
4) Based on previous neuroimaging L1 findings, we predict the native response for inflections to show dominance of the left hemisphere, whereas the response to derivations may not exhibit any hemisphere effects due to the commonly observed bilateral fronto-temporal network activation (although left-lateralised activity has also been reported; for extensive reviews, see e.g., Bozic & Marslen-Wilson, 2010; Leminen et al., 2018). The response topographies of the L2 learners presumably resemble the native patterns with increasing proficiency (as with L2 syntactic processing; Steinhauer, White, & Drury, 2009).

2. Methods

2.1. Participants

Fifteen native Finnish speakers (mean age 26 years, SD = 4.45; 5 male) and two groups of German native speakers, 15 beginners (mean age = 23.3, SD = 2.29; 6 male), and 15 advanced learners (mean age 27.4, SD = 2.69; 1 male) of Finnish participated in the study. Differences in gender were not significant [Kruskal-Wallis χ^2 (2) = 4.67, p = .097] whereas there was a significant difference between the age of the beginner and advanced group (Mann Whitney U = 22, p < .001). All participants were right-handed (assessed with the Oldfield (1971) inventory: mean LQ = 87, SD = 14.46) with normal hearing and no reported neurological, language or psychiatric disorders. All participants lived in Finland at the time of the study and none were early bilinguals; none of the German participants had started learning Finnish in early childhood. Most of the participants were recruited from university language courses. The level of Finnish proficiency was assessed with an online test, assessing vocabulary and grammar knowledge with reading and writing tasks, by the University of Helsinki Language Centre used for course placement. Thus, separate tests were administered for beginners and advanced learners in order to determine their proficiency within the Common European Framework of Reference for Languages (CEFR; Council of Europe, 2011). The language test for beginners was at CEFR A1.2 level (Basic user; mean score = 45.35, SD = 31.39, range = 3–90; test range 0–92), and for the more advanced learners at the B1.1 level (Independent user; mean score = 46.09, SD = 20.89, range = 23–84; test range 0–146). Test scores of four advanced learners were not acquired due to the online test made unavailable by the Language Centre at the time. However, their self-rated proficiency and daily language use did not significantly differ from the rest of the advanced learners (Mann-Whitney U-values ≥ 13, p-values > .36), and thus they were included in the study. History of Finnish language learning and use in the learner groups are reported in Table 1. Participants in all groups had learnt at least two foreign languages in addition to their native language [Learned languages: Natives 3.33, SD = .90; Beginners 3.13, SD = .83; and Advanced 4.00, SD = 1.00; Kruskal-Wallis χ^2 (2) = 4.26, p = .12]. All participants gave informed written consent and the study was accepted by the local ethics committee and conducted according to the Declaration of Helsinki.

2.2. Stimuli

The stimuli (Table 2) consisted of four real Finnish stems (*kuva* 'picture', *kirja* 'book', *kana* 'chicken', *kahvi* 'coffee', all high-frequency words in nominative case), as well as affixed words comprising the aforementioned stems combined with an existing derivational suffix (*-sto* 'collection of'), an existing inflectional suffix (*-sta* 'from', 'of'), and a pseudo-suffix that was acoustically similar to the inflectional suffix (*-spa*). Consequently, two existing stem + suffix combinations

Table 1 – Mean scores (SD) of L2 language history and use in the beginner and advanced L2 learner groups.

	Beginner	Advanced
AoA (years)	23.07 (2.22)	19.73 (4.01)
Proficiency[a]	1.00 (.00)	3.60 (.63)
Language use[b]		
Listening	1.93 (.96)	5.53 (.99)
Speaking	1.47 (.92)	4.80 (1.57)
Reading	1.47 (.74)	4.53 (1.81)
Writing	1.27 (.59)	3.87 (1.92)

All measures were significantly different between groups (tested with t- or Mann-Whitney U test).
[a] Self-rated in scale 1–5 (1 = elementary, 2 = limited working, 3 = minimum professional, 4 = full professional, 5 = native or bilingual proficiency).
[b] Hours per week on scale 1–6 (1 = <1; 2 = 1–3; 3 = 3–5; 4 = 5–8; 5 = 8–12; 6 = >12).

Table 2 – Stimuli and their morphological identity.

Stem	Suffix		
	Derivation 'a collection of something'	Inflection 'of/ from something'	Pseudo-suffix
	-sto	-sta	-spa
kuva (picture)	kuvasto (catalogue)	kuvasta	kuvaspa*
kirja (book)	kirjasto (library)	kirjasta	kirjaspa*
kahvi (coffee)	kahvisto*	kahvista	kahvispa*
kana (chicken)	kanasto*	kanasta	kanaspa*

Asterisk (*) indicates non-existing forms. 'Kahvisto' and 'kanasto' are novel derivations, i.e., they do not exist in the lexicon but the suffix has a morphological meaning and could be used to make new derivational words.

formed *existing derivations kuva**sto** 'picture-**collection** → catalogue' and *kirja**sto** 'book-**collection** → library'. Combinations of the existing derivational suffix *-sto* with the other two stems *kana* and *kahvi* constituted legal but non-existent *novel derivations* *kana**sto** 'chicken-**collection**' and *kahvi**sto** 'coffee-**collection**'. *Existing inflections* comprised the four stems combined with the suffix *–sta* (elative case, *'from'*, *'of'*, *'about'*). Phonologically and acoustically similar complex *pseudo-suffixed words* imitated the existing inflections. The lemma frequencies of the stems, derivations, and inflections were acquired from 430 corpora with 3,062,011,823 tokens provided by the Language Bank of Finland, FIN-CLARIN Consortium. The average frequency for stems was 37.86 instances per million (ipm; SD = 37.54, range = 6.37–83.56; log frequency 1.34, SD = .57), existing derivations 2.98 ipm (SD = 3.71, range = .36–5.61; log .15, SD = .84), and inflections 6.62 ipm (SD = 7.44, range = .42–16.63; log .48, SD = .72).

In addition, affixed filler words were created using the same four stems combined with another set of suffixes, differing in their phonological make-up from the experimental ones. An existing derivational suffix (*–la* 'a place') combined with stems *kahvi* and *kana* constituted existing derivations kana**la** ('a place for hens → a henhouse') and kahvi**la** ('a place for coffee → a coffee shop'), and legal but non-existent novel derivations *kuva**la** ('a place for pictures') and *kirja**la** ('a place for books'). In combination with each stem, the existing inflectional suffix *–lla* (adessive case, 'on', 'at') and a pseudo-suffix *-lo* formed further filler items.

The stimuli were produced by a female native Finnish speaker in a soundproof room and digitally recorded at 44.1 kHz sampling frequency as 24-bit mono sound. The durations of the selected stems were 272 msec (kuva), 303 msec (kana), 387 msec (kahvi), and 388 msec (kirja), and the speech signals were faded out by 20 msec. To counteract co-articulation biases in the final cross-spliced stimuli, the suffixes were uttered with a preceding non-complimentary vowel (i.e., vowels not naturally occurring at the end of the stems, e.g., 'espa'), which was stripped after the recording. All suffixes were 268 msec in duration and faded in by 5 msec and out by 15 msec. The F0 and loudness of the stems and suffixes were matched, after which the F0 of the suffixes was decreased by ~20 Hz (in accordance with the Finnish tonal structure; Suomi, 2007) and loudness by 3 dB. Finally, the stems were spliced with each of suffixes, separated by a silent gap of 10 msec, to form the affixed words. A native Finnish speaker verified the final stimuli as natural sounding. Stimulus preparation was conducted using Pro Tools 9 (Avid Technology, Inc., Burlington, MA, USA), Adobe Audition 3.0 (Adobe Systems Inc., San Jose, CA, USA) and Praat version 5.3.32 (Boersma & Weenink, 2001).

2.3. Experimental design and procedure

Stimuli were presented according to the multi-feature paradigm, in which every other stimulus is a standard and every other is an infrequent deviant that differs from the standard in some feature (Näätänen et al., 2004; Sorokin et al., 2010). In this case, each stem served as a standard in four blocks, one for each designated stem, and the corresponding affixed words served as deviants. The stems were presented 480 times, equalling 50% of the block. The remaining 50% of stimuli consisted of the stem + suffix combinations, which occurred equiprobably in every second position in random order within the sequence. The affixed filler words were used to balance the occurrence of derivations between blocks and in order to reduce repetition-induced response habituation effects (McGee et al., 2001; Woods & Elmasian, 1986). Thus the probability of each affixed word was 8.3%. Mean stimulus onset asynchrony (SOA) was 1300 msec, with ±50 msec jitter. The order of the blocks was randomised for each participant. While watching a silent film without subtitles, the participants listened to four blocks of auditory stimulation delivered via headphones using the NBS Presentation software (Neurobehavioral Systems, Albany, USA). Participants were instructed to focus on the film and ignore the auditory stimulation.

2.4. EEG recording and analysis

EEG was recorded using BioSemi ActiveTwo recording system (BioSemi, Inc., Amsterdam, Netherlands), with 128 active scalp electrodes fitted into an elastic cap following the BioSemi ABC position system. Additionally, three active electrodes were placed at the tip of the nose and at the left and right mastoid sites. Horizontal and vertical electro-oculogram (HEOG, VEOG) was monitored by bipolar leads. Data were recorded with a sampling rate of 512 Hz and a bandwidth of DC-104 Hz. The online reference was located close to the standard CP1 site. Using Analyser 2.0 (Brain Products, Germany), any bad channels were interpolated based on the surrounding electrode sites (Bendixen, Prinz, Horváth, Trujillo-Barreto, & Schröger, 2008; Perrin, Pernier, Bertrand, & Echallier, 1989). The data were re-referenced offline to the average of mastoid electrodes and filtered to .5–35 Hz. The independent component analysis (ICA) algorithm Infomax was applied to clean the data from eye movement and blink artifacts. The data were epoched -100-1000 msec relative to stimulus onset, after which additional artifacts exceeding a threshold of ± 100 μV were removed. The artifact rejection for epochs of this time interval ascertained that further analyses were made only to stimulus trials that were free of any artifacts. Although we employed the multi-feature paradigm

typically used to calculate mismatch negativity (MMN) responses, we chose to quantify the response amplitudes without subtractions (thus also preserving the signal-to-noise ratio) and compared the basic ERPs of different conditions following common practices in ERP analysis (for similar approach, see e.g., Shtyrov et al., 2011; Gansonre et al., 2018).

The data were then re-epoched into segments from −165 msec before specific deviation points (DP) for each stem + suffix combination until 370 msec thereafter, which was done to ensure maximally similar analysis settings for the morphologically (and thus acoustically) different stimuli. Namely, the time interval of 165 msec preceding the DP overlapped with the phoneme 's' at the start of each suffix, followed by a natural silent gap, which is why this interval was used for baseline correction. This enabled time-locking the ERP to the exact time-point at which the different suffixes diverged from each other, and the recognition of the suffix and thereby the meaning and legality of the full complex word form became possible. Stem + suffix combinations belonging to the same morphological category (Table 2) were averaged together. ERPs for the Existing derivation condition were produced by averaging together the two real derivations in the paradigm, while the Novel derivation was produced by averaging the two invalid combinations of stems and the derivational suffix '-sto'. Comparisons between Inflection and Derivation/Novel derivation were enabled by separately averaging the inflectional forms of the two stems that corresponded with either the stems of the existing or novel derivations, depending on which derivational contrast the inflection was to be compared with. The comparison between Inflection and Pseudo-suffixed words was acquired by averaging the four inflectional stimuli and the four pseudo-suffixed stimuli separately. The suffixes of filler words differed markedly from those of the experimental words in their acoustic-phonetic structure and hence prohibited direct comparisons, for which reason responses to fillers were not analysed here.

ERP response quantification was carried out by defining peaks and time windows after suffix deviation from a region-of-interest (ROI) of 120 most frontal channels (excluding channels posterior to POz and T7/8), where the responses were most prominent (see Supplementary Figs. 1–3). Using this ROI for each suffix and group average, we determined three suffix- and group-matching peaks at 60 msec and 130 msec and 200 msec after DP, similar to previously reported suffix-related response latencies (Leminen et al., 2016; Leminen, Lehtonen, et al., 2013; Leminen, Leminen, et al., 2013; Whiting et al., 2013). Mean response amplitudes were quantified for each suffix and group from 30 msec time windows around the first two responses and a larger time window 170–240 msec around the latest peak due to its longer response duration (see Figs. 1–4A).

2.5. Statistical analysis

In order to analyse the responses to each stem + suffix combination in each group, the sensor data were reduced to four ROIs covering symmetrically 2 × 21 channels in the anterior left and right hemispheres and 2 × 20 channels in the posterior left and right hemispheres (for channel locations, see schematic scalp map in Figs. 1–4B). Repeated measures ANOVA for suffix comparisons in each of the response time windows were administered separately for each group. Planned comparisons were performed between existing Derivation versus Novel derivation, Derivation versus Inflection, Novel derivation versus Inflection, and Inflection versus Pseudo-suffixed word, with additional factors Anterior-posterior axis and Hemisphere (left, right) in the repeated measures ANOVA to investigate topographical effects. Multiple comparisons were corrected for by using Bonferroni correction on any interactions, main effects, and post hoc pairwise comparisons. As we did not have any predictions of age effects in these groups of young adults (20–34 years), we did not include age as a factor in our statistical analyses despite the difference between the learner groups.

3. Results

3.1. Derivations versus inflections

The early positive response at 60 msec did not demonstrate significant differences between derivations and inflections in any of the groups (Fig. 1). As depicted in Supplementary Fig. 1A, in the Native speakers, irrespective of suffix, an interaction of Anterior-posterior and Hemisphere [$F(1,14) = 7.54$, $p = .032$] indicated more prominent anterior than posterior responses (right hemisphere: $p = .006$, left: $p = .058$), and the weaker posterior responses were stronger in the left hemisphere ($p = .02$). In the Advanced L2 learners, a significant Suffix × Anterior-posterior axis × Hemisphere interaction [$F(1,14) = 7.67$, $p = .03$] displayed larger amplitudes in the anterior than posterior sites (p-values < .002) across suffixes, as well as a significant hemispheric difference in the posterior sites specific to the response to derivations, which was more prominent in the left than right hemisphere ($p = .017$). Beginners' responses at this latency yielded no significant differences in topographical distribution (all p-values > .2).

The early negative response at 130 msec was stronger to derivations than inflections in the Native speakers [$F(1,14) = 10.17$, $p = .014$], and this difference was also found in the anterior sites in the Beginners [$F(1,14) = 7.35$, $p = .034$; Fig. 1B]. Topographical analysis showed generally more pronounced responses anteriorly in the Native group [$F(1,14) = 9.78$, $p = .014$; Supplementary Fig. 1B]. The Advanced group, on the other hand, showed a significant Suffix × Hemisphere interaction [$F(1,14) = 7.71$, $p = .03$], whereby the response to inflections was left-lateralised. Beginners showed a significant Anterior-Posterior × Hemisphere interaction [$F(1,14) = 23.67$, $p < .001$] by which, similarly to the Native speakers, responses were stronger in anterior sites (p-values < .014), whereas posterior responses were right-lateralised ($p = .002$).

The late long-lasting negativity at 170–240 msec evinced only marginally significant differences between the suffixes in the Natives and Beginners (Fig. 1B). Native speakers elicited stronger responses to derivations than inflections in the left hemisphere [$F(1,14) = 6.20$, $p = .052$]. The Advanced group did not show significant differences between suffixes, and

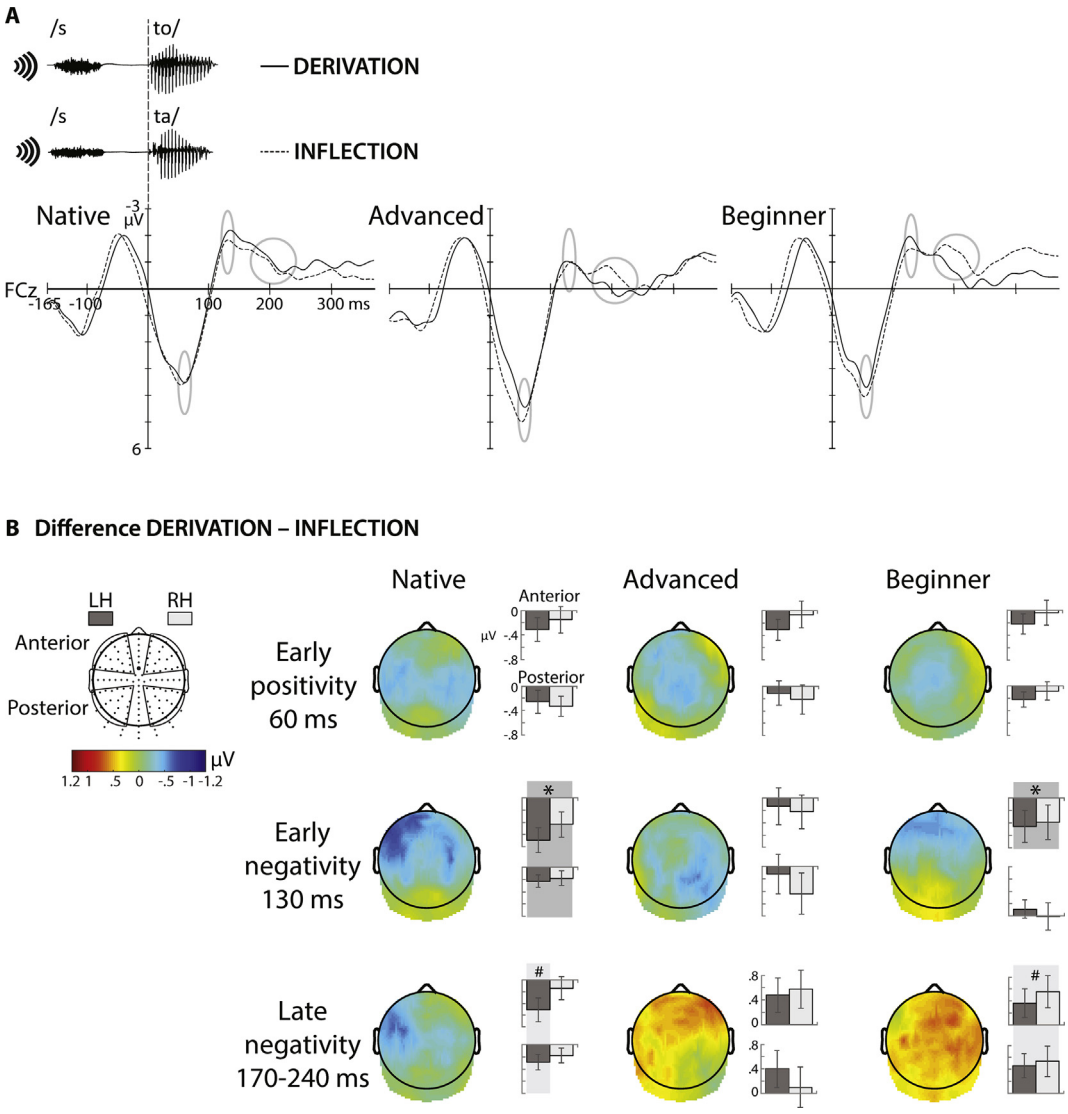

Fig. 1 – Event-related responses to existing derivations and inflections. (A) ERPs to suffixes of derivations (solid line) and inflections (dashed line) preceded with identical stems. The speech waveforms of the two suffixes relative to the ERPs show the temporal coincidence of the speech information and the neural responses. The y-axis depicts the deviation point in time when the identity of the suffix becomes temporally possible to be recognised. The grey circles denote the response time windows used in the analysis. ERPs are shown at a representative channel FCz. (B) The schematic channel map on the left illustrates the anterior and posterior ROIs in the left and right hemispheres used in the analysis. Derivation minus inflection difference scalp maps and response differences in each of the ROIs in each group and time window. Error bars denote SEM. *$p < .05$, # $.05 \geq p \leq .06$. The grey highlighted areas indicate the ROIs with significant differences.

Beginning learners showed a marginally significant effect, opposite to the Natives, of larger responses to inflections than derivations across hemispheres [F (1,14) = 4.59, $p = .1$]. Both learner groups demonstrated generally stronger responses in the anterior than posterior sites [F (1,14) > 6.04, p-values < .023; Supplementary Fig. 1C].

3.2. *Derivations versus novel derivations*

For this comparison, the Native group demonstrated a significant interaction of Suffix × Hemisphere [F (1,14) = 7.99, $p = .026$] at the early 60 msec latency. This was due to the response for novel compared to existing derivations being more positive in both hemispheres (p-values < .008; Fig. 2B), whereas the response to existing derivations was larger in the left than right hemisphere and vice versa for the novel derivations (Supplementary Fig. 1A). Furthermore, an interaction of Anterior-posterior axis × Hemisphere [F (1,14) = 12.14, $p = .008$] showed that the early positivity was generally stronger in the right than left anterior sites ($p = .027$) and marginally stronger in the left than right posterior sites ($p = .051$; Supplementary Fig. 1A). In the Advanced learners, significant Suffix × Anterior-posterior × Hemisphere interaction [F (1,14) = 9.51, $p = .016$] indicated that the response to novel derivations was more positive than to existing derivations, as in Natives, but in anterior sites only (p-values < .047;

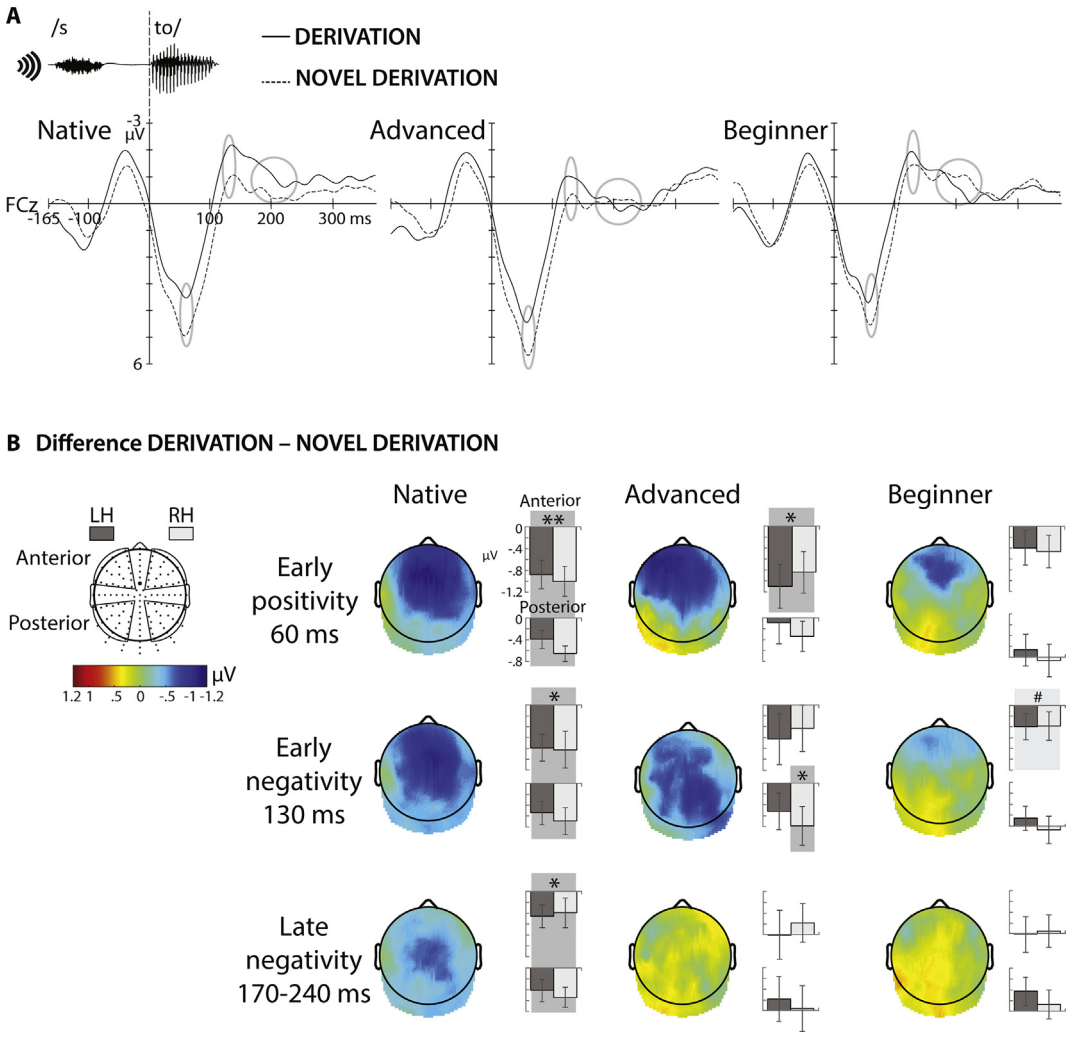

Fig. 2 – Event-related responses to existing and novel derivations. (A) ERPs to existing derivations (solid line) and novel combinations of stem + derivational suffix (dashed line). Both word types ended with the same derivational suffix, but they were combined with different stems that either constituted derivations that exist in the lexicon or novel derivations that are not in the lexicon but are linguistically plausible. The temporal co-occurrence of the suffix waveform and the ERP is illustrated. The y-axis depicts the deviation point in time when the identity of the suffix becomes temporally possible to be recognised. The grey circles denote the response time windows used in the analysis. ERPs are shown at a representative channel FCz. (B) The schematic channel map on the left illustrates the anterior and posterior ROIs in the left and right hemispheres used in the analysis. Existing minus novel derivation difference scalp maps and response differences in each of the ROIs in each group and time window. Error bars denote SEM. $^{*}p < .05$, $^{**}p < .01$, # $.05 \geq p \leq .06$. The grey highlighted areas indicate the ROIs with significant differences.

Fig. 2B). Furthermore, while the responses were generally more enhanced in anterior than posterior sites (*p*-values < .002) as shown in Supplementary Fig. 2A, the response to existing derivations was stronger in the left than right hemisphere in the posterior region ($p = .017$). In the Beginner group, the anteriorly pronounced difference between existing and novel derivations did not reach significance (Fig. 2B). Significant Suffix × Anterior-posterior axis interaction [$F(1,14) = 11.92$, $p = .008$] indicated that the response to novel derivations was stronger in the anterior than in the posterior sites ($p = .008$; Supplementary Fig. 2A), whereas no such difference was found for the response to existing derivations ($p = .375$).

Following the early positivity, the negative response at 130 msec was stronger for existing than novel derivations [$F(1,14) = 8.34$, $p = .024$; Fig. 2B], and in the anterior than posterior region across suffixes [$F(1,14) = 17.09$, $p = .002$] in the Native speakers (Supplementary Fig. 1B). In the Advanced learners, a significant interaction Suffix × Anterior-posterior × Hemisphere [$F(1,14) = 9.02$, $p = .02$] defined similar response difference between the suffixes as in the Natives, but was pronounced in the right posterior ROI ($p = .047$; Fig. 2B). Post hoc pairwise comparisons also showed that the response to novel derivations was more pronounced in the anterior than posterior sites ($p = .049$; Supplementary Fig. 1B). In the Beginning learners, the stronger response to

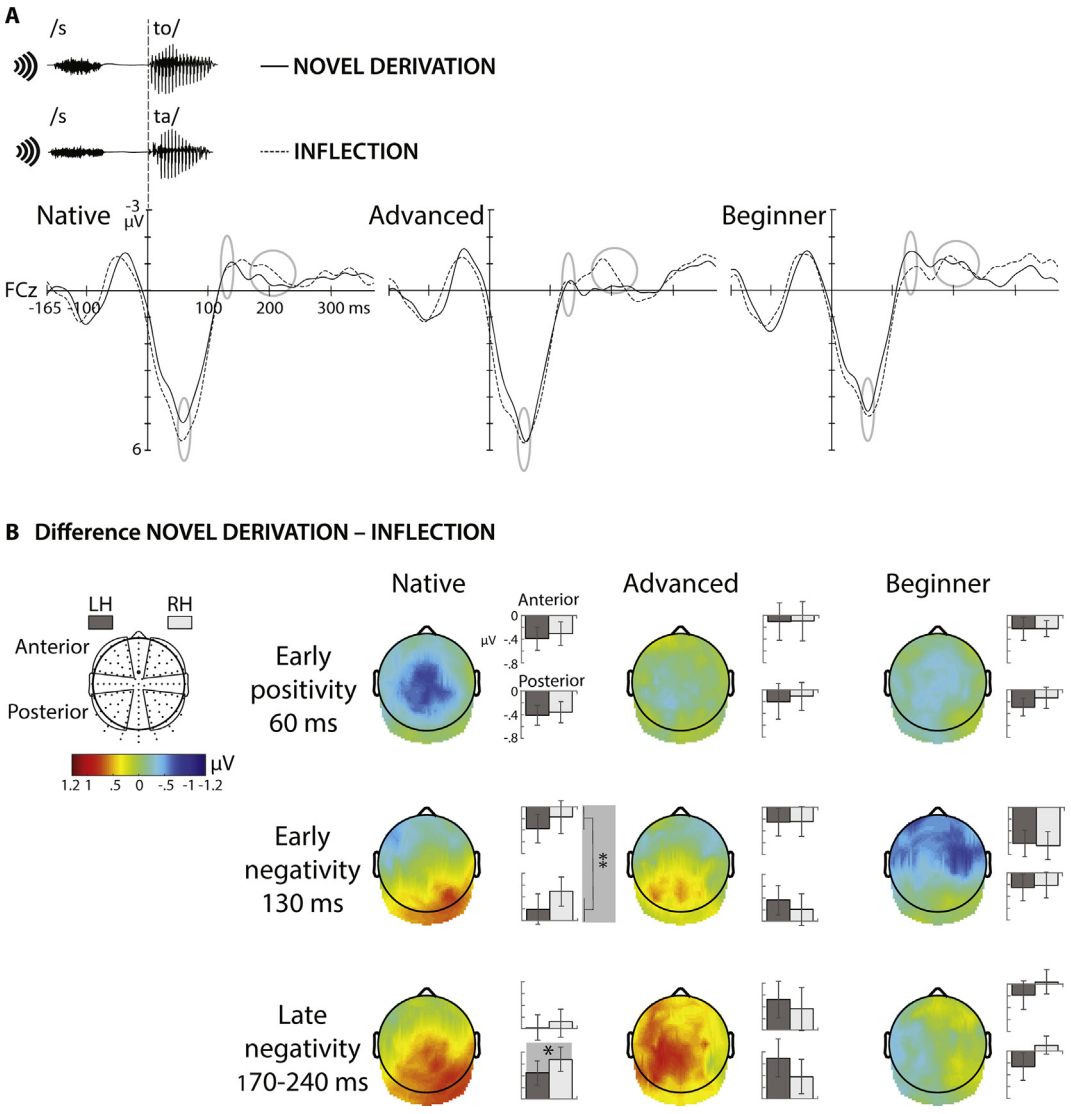

Fig. 3 – Event-related responses to novel derivations and inflections. (A) ERPs to suffixes of novel derivations (solid line) and inflections (dashed line) preceded with identical stems. The speech waveforms of the two suffixes relative to the ERPs show the temporal coincidence of the spoken suffix and the neural responses. The y-axis depicts the deviation point in time when the identity of the suffix becomes temporally possible to be recognised. The grey circles denote the response time windows used in the analysis. ERPs are shown at a representative channel FCz. (B) The schematic channel map on the left illustrates the anterior and posterior ROIs in the left and right hemispheres used in the analysis. Novel derivation minus inflection difference scalp maps and response differences in each of the ROIs in each group and time window. Error bars denote SEM. $^{*}p < .05$, $^{**}p < .01$. The grey highlighted areas indicate the ROIs with significant differences.

the existing over novel derivations was marginally significant in the anterior sites [F (1,14) = 6.21, $p = .052$; Fig. 2B]. Further, a significant Anterior-posterior axis × Hemisphere interaction [F (1,14) = 13.42, $p = .006$] indicated that the responses were generally enhanced over the anterior scalp locations (p-values < .007), and in the posterior sites right-lateralised ($p = .016$; Supplementary Fig. 1B).

In the late time interval at 170–240 msec, the response to existing derivations was again stronger than to novel derivations in the Native group only [F (1,14) = 7.36, $p = .034$; Fig. 2B]. A significant main effect of anterior enhancement was found in the Native speakers [F (1,14) = 9.47, $p = .016$], Beginners [F (1,14) = 11.98, $p = .008$], and marginally significant in the Advanced group [F (1,14) = 5.82, $p = .06$] across the word types, shown in Supplementary Fig. 2C.

3.3. *Novel derivations versus inflections*

The early positive response did not show significant differences between novel derivations and existing inflections in the learner groups (Fig. 3B) and failed to reach significance in the Native speakers [F (1,14) = 5.46, $p = .07$]. In all groups

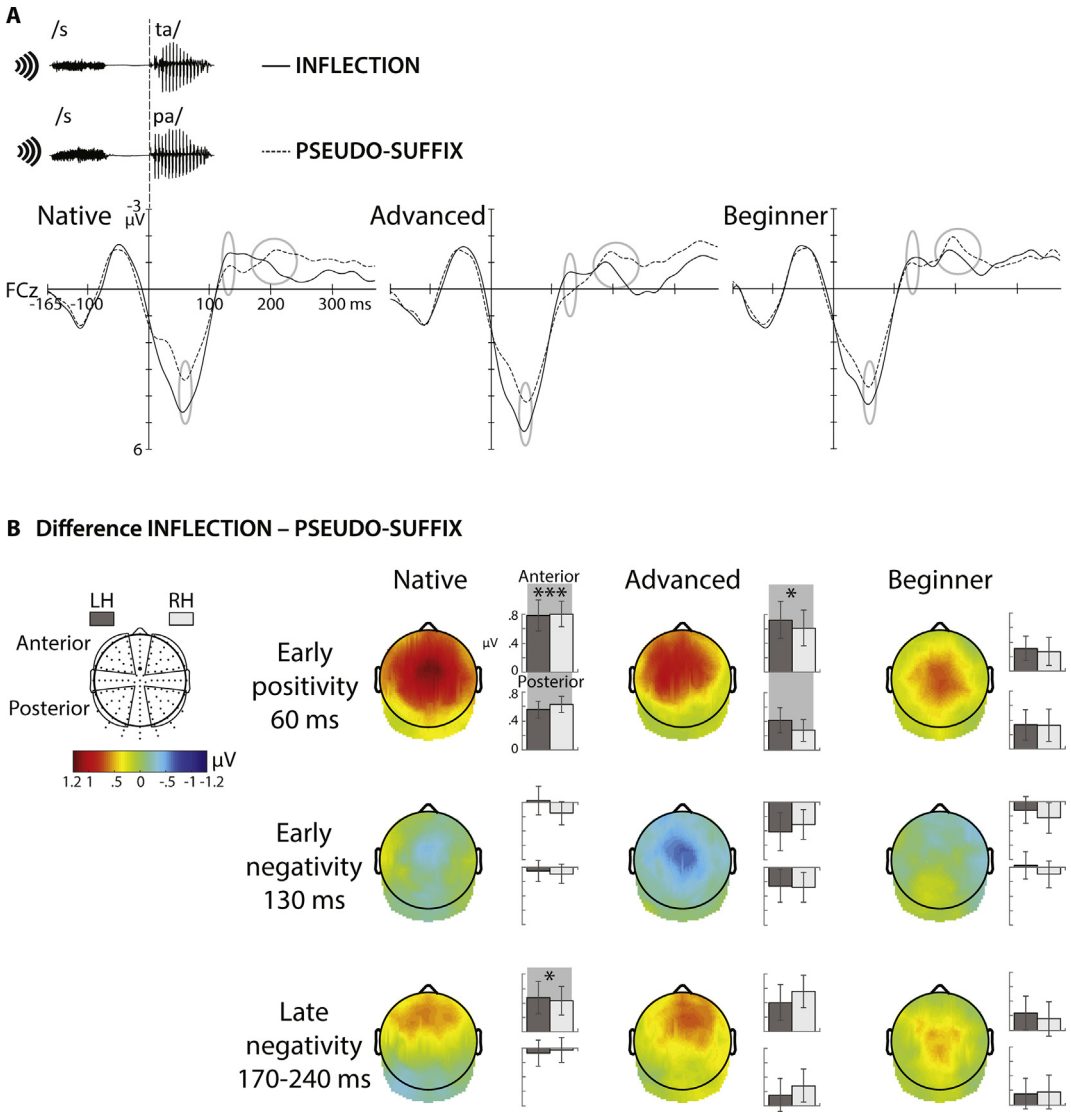

Fig. 4 – Event-related responses to inflections and pseudo-suffixed words. (A) ERPs to suffixes of inflections (solid line) and pseudo-suffixed words (dashed line) preceded with identical stems. The speech waveforms of the two suffixes relative to the ERPs show the temporal coincidence of the spoken suffix and the neural responses. The y-axis depicts the deviation point in time when the identity of the suffix becomes temporally possible to be recognised. The grey circles denote the response time windows used in the analysis. ERPs are shown at a representative channel FCz. (B) The schematic channel map on the left illustrates the anterior and posterior ROIs in the left and right hemispheres used in the analysis. Inflection minus pseudo-suffixed word difference scalp maps and response differences in each of the ROIs in each group and time window. Error bars denote SEM. $^{*}p < .05$, $^{***}p < .001$. The grey highlighted areas indicate the ROIs with significant differences.

response strength across suffixes was higher in the anterior than posterior region [F (1,14) > 11.17, *p*-values < .01; Supplementary Fig. 2A].

The early negativity (at 130 msec) showed more complexity in the suffix response patterns. In the Native group, Suffix had interactions with Anterior-posterior axis [F (1,14) = 17.52, $p = .002$] and Hemisphere [F (1,14) = 7.50, $p = .032$], whereby the difference between the response enhancement to novel derivations (compared to inflections) in anterior and the enhancement to inflections in the posterior sites was significant (Fig. 3B). Further, novel derivations elicited stronger anterior than posterior responses ($p = .002$). The hemispheric interaction was due to more pronounced response to novel derivations over the left than right hemisphere, whereas response to inflections was right–lateralised (Supplementary Fig. 2B). In the Advanced L2 learners, the response magnitudes to the suffixes did not differ significantly, but similarly to the Natives, a Suffix × Anterior-posterior interaction [F (1,14) = 7.24, $p = .036$] exhibited stronger anterior than posterior responses to novel derivations (post hoc pairwise $p = .059$; Supplementary Fig. 2B). Beginners, on the other hand, demonstrated generally stronger responses in the anterior

sites [F (1,14) = 10.49, $p = 012$], and the main effect of stronger response to novel derivations than inflections approached significance [F (1,14) = 5.32, $p = .074$; Fig. 3B].

The late negative response (170–240 msec) was significantly stronger to inflections than to novel derivations in the posterior sites ($p = .015$) in the Native speakers (Fig. 3B), whose response to novel derivations was larger in the anterior than posterior area ($p = .006$; Supplementary Fig. 2C). Both of these effects were evinced by a significant Suffix × Anterior-posterior interaction [F (1,14) = 8.79, $p = .02$]. No significant differences between the responses to suffixes were found in the learner groups. Responses were generally stronger in the anterior region in the Beginning learners [F (1,14) = 8.20, $p = .026$; Supplementary Fig. 2C].

3.4. *Inflections versus pseudo-suffixed words*

Comparison of inflected words and words with a pseudo-suffix differing in one phoneme from the real inflection showed early response differences. The positive response (60 msec) was greater to inflections than to pseudo-suffixes in the Native speakers [F (1,14) = 26.68, $p < .001$] and Advanced L2 learners [F (1,14) = 6.57, $p = .023$], as shown in Fig. 4B. Topographically, the Native speakers exhibited an interaction of Anterior-posterior × Hemisphere [F (1,14) = 5.43, $p = .035$], whereby responses irrespective of the suffix were generally more enhanced in the anterior area (p-values < .016), and left-lateralised in the posterior regions ($p = .051$). The learner groups showed enhanced responses at the anterior compared to posterior sites [F (1,14) > 7.53, p-values < .016]. The topographies are shown in Supplementary Fig. 3A.

The early (130 msec) negative response to inflections and pseudo-suffixed forms, in contrast, did not differ significantly in any of the groups (Fig. 4B), nor showed any topographical effects in the Native and Advanced learner groups. The Beginners demonstrated stronger overall response magnitude in the anterior than posterior sites [F (1,14) = 10.94, $p = .005$] and right-lateralised posterior responses ($p = .016$; Supplementary Fig. 3B).

At the late (170–240 msec) time interval, a significant interaction of Suffix × Anterior-posterior axis was established in the Native speakers [F (1,14) = 8.61, $p = .011$]. Post hoc comparisons revealed that the response elicited to pseudo-suffixes was stronger than that to inflections at anterior sites ($p = .046$; Fig. 4B). Furthermore, the response to pseudo-suffixed forms was significantly more prominent in the anterior than posterior region ($p < .001$; Supplementary Fig. 3C). Across the suffix types, the response was also right-lateralised in the Natives [F (1,14) = 8.50, $p = .011$]. In the learner groups, responses across the suffix types showed an anterior prominence [F (1,14) > 15.92, p-values < .002; Supplementary Fig. 3C], but no significant differences were found between the suffixes.

4. Discussion

We investigated the neural correlates of processing of morphologically complex words in native speakers and L2 learners. We presented native speakers, as well as beginning and advanced L2 learners of Finnish with existing derived words, existing inflected words, novel derivations (novel combinations of stem + existing suffix), as well as pseudo-suffixed words (stem + pseudo-suffix) in a passive listening paradigm. We observed triphasic ERP responses to each suffix, time-locked to the suffix deviation points. An early positivity (at 60 msec) was followed by an early negative response at 130 msec, and a further longer-lasting negative deflection at around 200 msec. Responses to the different kinds of morphological types were contrasted for each group separately in order to examine group-specific relative differences between different existing morphological forms as well as non-existing ones. We propose that the generated ERP response patterns demonstrated the temporal dynamics of early automatic morphological decomposition, followed by full-form access of the lexicalised items, and later second pass morphosyntactic parsing, present in full scale in the L1 processing. In the L2 learners, we observed a tendency for native-like response patterns with increasing proficiency, yet with some qualitative differences. Below, we will discuss each of these main findings in detail.

4.1. *Effects of morphological contrasts*

Starting with the processing of **derivations** and **inflections**, this contrast established no differences between the suffixes in the early 60 msec response (after the deviation point) in any of the groups. Since both suffixes were plausible continuations for the stems, with existing suffixes, this early response tentatively reflects early morphological decomposition, echoing the accounts of similar initial parsing strategies for derivations and inflections (e.g., Lewis et al., 2011; Marslen-Wilson & Tyler, 2007; Rastle & Davis, 2008; Whiting et al., 2013; Whiting, Shtyrov, & Marslen-Wilson, 2015).

At 130 msec, the native speakers elicited a larger negativity to the existing derived words as opposed to the inflections, corroborating earlier findings of similar negative responses at similar latencies (~100–170 msec) to derivations in passive oddball paradigms, suggesting full-form lexicalised storage of familiar derivations (Leminen, Leminen, et al., 2013; Whiting et al., 2013; Hanna & Pulvermüller, 2014). At this time-point, the morphological category of the suffix was fully identifiable, and hence, the greater response to derivations putatively indicates activation of stronger full-form long-term memory traces compared to inflections. Presumably, inflections elicit a weaker response due to absent (or weak at best) full-form memory traces, whereas stem-affix priming reduces activation of the affix memory trace as such. This finding is in line with previous behavioural and neurocognitive findings with correctly inflected and derived Finnish words. Namely, inflected words in L1 have typically elicited more errors, longer reaction times, and larger N400/LAN-type of ERP/ERF responses than matched monomorphemic and derived words (Lehtonen et al., 2007, 2012; Leinonen et al., 2009; Leminen et al., 2011; Vartiainen et al., 2009). This has been interpreted to reflect morphological processing cost of morpheme parsing of inflections and later composition, taking place at a more central, semantic-syntactic level of processing (for more detailed discussion, see e.g., Laine, Niemi, Koivuselkä-Sallinen, Ahlsén, & Hyönä, 1994). In contrast, behavioural responses to existing derivations have not, in most cases, differed from those to monomorphemic words, which has

been taken as evidence for their full-form storage (Bertram, Laine, & Karvinen, 1999; Vannest, Bertram, Järvikivi, & Niemi, 2002) or dual-route processing (Leminen, Leminen, et al., 2013). Our current temporally precise findings in native speakers show that while full-form representations seem to be present for derivations, accessed at 130 msec after the full-form can be recognised, there seems to be a very early (<100 msec) parsing process similar to both inflections and derivations, supporting the (likely weaker) dual-route processing of such items as well.

In the L2 speakers, the stronger response to derivations compared to inflections at 130 msec was also significant, but only in the beginners, however restricted to the anterior region. It is possible that while more advanced learners are already aware of the underlying morphology of the derivational forms, their parsing efforts are not as fully automatised as in native speakers. Only marginally significant effects were observed in the latency of 170–240 msec, showing a continued enhancement for derivations over inflections in the left hemisphere of the native speakers, referring to continued lexical memory-trace activation, and an opposite effect in the beginners. In addition, similar to the early negativity, there was a non-significant difference between the suffixes in the advanced learners. The effect of inflections producing greater response than derivations at this latency may indicate prolonged parsing of the inflectional forms. The findings imply discrepancy in the processing of L2 derivations and inflections between the beginners and more advanced learners. Surprisingly, the early negative response suggests that the processing of derivations was more native-like in the beginners than in the advanced group. In contrast, this effect was reversed only 50–110 msec later, when the response to derivations had decreased and the response to inflections increased, possibly suggesting short-lived lexical activation of the derivations and longer-lasting parsing efforts of the inflections in the beginning learners, compared to the higher-proficient learners and native speakers.

Comparing responses to two different suffixes is not sufficient to inform about the degree of full-form storage/parsing of derivations in the native and learner groups. To get more direct evidence of the processing characteristics for derivations, a more direct comparison of acoustically identical suffixes in the context of plausible but non-existing (novel) combinations of stem + suffix was obtained.

The processing of **existing** compared to **novel derivations** produced a stronger early positivity to novel than existing derivations in the native speakers, possibly reflecting an attempt to parse the novel form into morphological constituents. Advanced L2 learners showed the same response difference but the effect was restricted to the frontal area. Beginning learners' responses did not differ from each other at this latency. Following the positive response, the early negativity was stronger for existing derivations than novel combinations (as with the comparison to inflections) in the native speakers and, in the right posterior area, in advanced L2 learners. In the beginners, there was a trend towards existing derivations eliciting greater negativity than novel derivations in the anterior region. Again, similar to the derivation versus inflection contrast, native speakers manifested a long-lasting enhancement of the existing derivations over the novel ones reaching the late 170–240 msec time interval, absent in the learner groups.

The larger positivity to the novel derivations in the native and advanced L2 speakers might reflect greater effort in early parsing of these non-existing combinations. In this comparison of suffixes, it was possible to recognise their legality soon after the plosive consonant. For the novel combinations, the probability of encountering the derivational suffix after the stems was lower than for the existing derived words, and hence, the early positivity possibly set forth lexical access of the real derivations. Importantly, the effect of stronger negative response to the existing than novel derivations, starting at the 130 msec latency may indicate the full-form lexical activation for the existing derivations, demonstrated in all the groups to different extent, as opposed to the weaker response to the combinations that lacked prior memory representations (Hanna & Pulvermüller, 2014). The existence of the late enhancement to derivations in the natives could represent sustained memory-trace activation.

Although not statistically significant, beginners showed a hint of early latency activation difference in the processing of the existing and novel derivations in the frontal sites akin to that of the advanced learners. Further, beginners demonstrated a marginally significant frontal enhancement to the existing derivations in the early negativity. This may indicate that beginners had indeed developed full-form memory traces for the common derivations ('kirjasto'/'library' and 'kuvasto'/'catalogue') used in this study, suggesting rapid development of long-term lexical representations for frequently occurring derivations in adult L2 learners.

We also compared **novel derivations** with **inflections**, the processing of which we expected to reflect weak or non-existent lexical full-form memory-trace activation to both word types. At the early 60 msec latency, all groups lacked significant early response difference between these suffixes, analogous to that between existing derivations and inflections, suggesting similar automatic parsing of both word types. Curiously, in the second time-window (130 msec), the direction of the native response difference significantly interacted in the anterior–posterior plane, such that the response to novel derivations was stronger than to inflections in the anterior area and vice versa in the posterior sites. Although the differences between these suffixed words were not significant *per se*, the bipolar topography indicates that the two types of suffixed words activated neuronal populations with distinct origins. On the other hand, no activation of full-form memory traces to either novel derivations or inflections was expected, expressed as a lack of differences in the response amplitudes, and this was indeed what we observed. The advanced learners elicited a native-resembling but non-significant response difference pattern, whereas beginners showed a tendency towards greater fronto-central responses to novel derivations than to inflections. These patterns might again indicate increasing similarity to native processing in the use of neural resources with increasing L2 proficiency. The late response showed a continuation of the earlier posterior effect of inflections establishing greater responses than novel derivations in the native group. Likewise, the advanced learners showed consistency in mimicking the response difference in the natives, however, statistically not significantly, while beginners exhibited no difference. The posterior enhancement of inflections over the novel

derivations may be accounted for sustained morphological processing cost inherent to inflections that putatively require online parsing. The lack of neural memory traces or other kind of morphological legality for the novel derivations seem to have yielded weak activation at 130 msec, and a further drop in response strength at the 170–240 msec latency, especially in the native and advanced groups.

Finally, we compared **inflections** with **pseudo-suffixed words** in order to find out whether the online parsing of inflectional suffixes, which putatively do not constitute lexicalised forms, differs from the processing of pseudo-suffixes not present in the L2 morphology. The comparison between existing inflections and word stems combined with a phonologically closely matching pseudo-suffix showed an early more pronounced positive response to inflections than to pseudo-suffixed forms in the native and advanced L2 speakers. Beginners also showed a non-significant trend towards a similar effect. The distinction between the two suffixes was acoustically possible immediately after the deviation point (time zero of the ERP) and simultaneously it became morphologically conceivable to determine whether the heard item was a real or non-existing form; there are virtually no words in Finnish with an 's' after the base stem that are followed by a 'p'. Hence, the recognition of the pseudo-suffix was near-simultaneous with the onset of the spoken suffix, and the smaller response could account for immediate reduction of parsing.

The early negative (130 msec) response was not significantly different between the suffixes, possibly reflecting the lack of long-term memory-trace activation of the full form in either case. At the latest time interval, the response to pseudo-suffixes was greater than to inflections in the anterior regions in native speakers, reflecting a delayed, second-pass morphosyntactic/reanalysis ERP pattern (Leminen et al., 2016; Shtyrov, 2010). This anterior ERP signature corroborates findings of syntactic violations eliciting larger effects than morphosyntactically correct ones (Brunelliere et al., 2007; Hasting et al., 2007; Hasting & Kotz, 2008; Menning et al., 2005; Pulvermüller & Assadollahi, 2007; Pulvermüller et al., 2008; Pulvermüller & Shtyrov, 2003). This pattern was not significant in the learner groups, but a tendency was observed with increasing aptitude. Overall, the automatic recognition of existing inflections was evident in the more advanced learners, while such automaticity had not yet developed in the beginners.[1]

4.2. *Topography effects in the native and L2 learner groups*

In addition to the suffix contrasts, examination of the original response topographies of each suffixed word type showed some indications of gradual change in the function of the underlying language network for the L2. The deflections to all of the suffixed word types demonstrated fronto-central response scalp distributions, commonly found for spoken word forms in the ERP literature (e.g., Shtyrov et al., 2011; Leminen, Leminen, et al., 2013; Whiting et al., 2013). This was true in all groups, shown by the anterior ROIs typically establishing greater responses than the posterior ones.

In the native and advanced L2 speakers, the early parsing (60 msec) of derivations showed left-lateralisation (see also De Grauwe, Lemhöfer, Willems, & Schriefers, 2014; Whiting et al., 2013), however this was observed only in the generally less activated posterior region in the advanced learners. In contrast, the initial decomposition of inflections did not show hemispheric effects. In the next phase of activation (130 msec), the response to inflections in the more advanced learners showed a left prominence, whereas the native response was lateralised to the right hemisphere. At this latency, native speakers showed stronger left than right hemisphere response to novel derivations. Beginners, on the other hand, manifested a pattern of stronger right than left hemisphere recruitment of the posterior areas across all word types. The final phase (170–240 msec) of processing did not show hemisphere effects in the L2 learners, but the native response to both inflections and pseudo-suffixes was greater in the right than left hemisphere.

In the absence of source reconstruction (not employed here due to the limitation of the relatively small n in each group), the conclusions for the neuronal structures underlying the observed effects should be extremely cautious. Nevertheless, the findings especially for the existing derivations indicate native-like automatic early parsing, originated from the left hemisphere, in the advanced L2 group. Such findings would also be in line with the Declarative/Procedural model (Morgan-Short & Ullman, 2011; Ullman, 2001b), demonstrating the importance of language experience in developing automatic parsing of morphology. Compared to beginning L2 learners, advanced learners may have shifted towards procedural memory instead of declarative memory, at least for early parsing of derivations. The topographical effects of the processing of inflections and novel combinations of existing morphemes, on the other hand, point towards discrepant hemispheric engagement between all groups. Namely, while L2 beginners had a tendency for right hemisphere dominance at the early negativity in general, the advanced L2 learners and native speakers showed more specific, yet distinct, hemisphere effects to these word types. This implies that in adult L2 acquisition, processing of inflections may not reach native-like automaticity and/or requires an extensive period of language experience to generate neural activation similar to native processing (Liang & Chen, 2014).

5. Conclusions

The L2 learners manifested a gradual effect of proficiency towards L1-like responses to morphologically complex words. The advanced L2 learners showed early parsing of derivations and inflections while the processing of L2 beginners seemed to rely more on the activation of the full-forms of derivations.

[1] We minimised the possible confounds of language transfer from the L2 learners' native language by carefully designing stimuli not overlapping with their L1 German lexicon. Furthermore, Finnish belongs to the Finno-Ugric language family and German to the Indo-European Germanic branch. Importantly, as the L2 groups shared the same L1, the unlikely language transfer effects in the ERP patterns would have been of similar magnitude in both L2 groups. Thus, conclusions between the low and high proficiency groups based on language transfer are not compelling.

While the native response to derivations implied a dual mechanism of early parsing and full-form access, the L2 learners' response to derivations referred to a shift from full-form access only to parsing effort with increasing proficiency. The results imply a gradual increase of similarity in the responses to derivations with increasing proficiency, showing that the advanced group is sensitive to morphological information (Dal Maso & Giraudo, 2014; Deng et al., 2016). The processing of inflections indicated distinct parsing patterns in each group. Native speakers exhibited two-phase parsing of inflections, whereas advanced learners showed similar early parsing only and beginners little inflection-specific early parsing but instead showed signs of late parsing effort. Our findings corroborate previous neuroimaging findings on inflectional processing (Pliatsikas, Johnstone, & Marinis, 2014), suggesting that late L2 learners do decompose inflected words into their constituents; we could not find clear evidence for holistic processing. The differences in the topographies suggest that the underlying function of the language network governing morphological processing changes from recruitment of the right hemisphere circuits in early stages of L2 morphology acquisition to more native-like, left- and bilateral activation. In general, our findings support the convergence hypothesis (e.g., Green, 2003), such that neural differences between native speakers and L2 learners decrease or even disappear as proficiency increases (see also e.g., Steinhauer et al., 2009). Furthermore, the automaticity with which advanced L2 learners process L2 morphology also suggests a shift towards procedural memory, supporting the Declarative/Procedural model (Morgan-Short & Ullman, 2011; Ullman, 2001a, 2001b). Finally, our findings corroborate previous ERP evidence on L2 morphosyntax that proficiency rather than age of acquisition might predict ERP patterns in L2 morphological processing, gradually transitioning towards L1-like patterns with higher levels of proficiency (Hanna et al., 2016; for review, see Steinhauer et al., 2009).

Data availability

The data are available from the corresponding author on reasonable request and approval of ethics committee.

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Supplementary data

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